Technology Concepts to Improve Knowledge Sharing During Maintenance

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***Abstract*—Industrial maintenance is a complex and knowledge-intensive field. Maintenance technicians need to have special professional skills and easy access to versatile and situationally relevant knowledge. The aim of this paper is to understand the nature and needs of maintenance work and to propose new technology concepts so as to support knowledge gathering and sharing. As a result of studies in two maintenance cases, it was found that communication between different actors is a key element in maintenance. Therefore, three different technology concepts were proposed in order to support and enhance communication. These concepts include augmented reality and wearable technologies that will provide new and efficient ways to help maintenance technicians in gathering and sharing task-specific information and long-term knowledge. In the next phase of this on-going research project, these technology concepts will be tested and evaluated with maintenance technicians.**

Keywords: maintenance; knowledge; technology concept; augmented reality; wearables.

I. Introduction

The nature of maintenance work can be described as a “combination of all technical, administrative and managerial actions during the life cycle of an item intended to retain it in, or restore it to, a state in which it can perform the required function” [1]. Reason [2] defines maintenance activities as (1) unscheduled operations, including corrective maintenance, and disturbance- and failure-preventive operations (opportunity-based maintenance); (2) scheduled disturbance- and failure-preventive operations; (3) inspections; and (4) calibration and testing.

To define knowledge in a maintenance task, it is important to understand different types of knowledge: explicit and tacit. Explicit or codified knowledge refers to knowledge that is transmittable in formal, systematic language [3]. Tacit knowledge has a personal quality, which makes it hard to formalize and communicate. Tacit knowledge is deeply rooted in action, commitment, and involvement in a specific context [4]. In addition, it is essential to distinguish knowledge from information and data. For this purpose, Mertins et al. [5] use a continuum ranging from data via information to knowledge in knowledge management. Data can be facts and figures which relay something specific, but are not organized in any way. Information is a flow of messages, while knowledge is created and organized by the very flow of information, anchored in the commitment and beliefs of its holder [4]. We consider communication here as a means to share knowledge.

Several studies have compared augmented reality (AR) technologies and the more traditional ways to provide maintenance instructions [6][7][8][9][10][11][12]. By definition, AR allows the user to see the real world, with virtual objects superimposed upon or composited with the real world [13]. Results suggest that AR technologies are usable in providing instructions because they are often faster to use, errors occur less frequently, and operators approve of the use of the technology. Nee et al. [14] have summarised a few AR-assisted maintenance systems. There are only few studies about the use of AR for remote collaboration where service personnel can discuss with each other [15][16].

Baber et al. [17] have shown that wearable computing human-computer interaction can be divided into three main activities: (1) using interaction devices; (2) using display devices, and (3) domain activity. Their study also considers what kind of dialogues these activities generate. New wearable technology solutions, such as head-mounted displays (HMD) and smart watches, enable new interaction methods and online connectivity in an industrial environment. In the military domain, various HMDs and wearable solutions have been developed and tested in future soldier projects for example [18][19][20]. For industrial maintenance, however, demonstrators and concepts of wearable maintenance systems have been developed [21][22], but – to the best of our knowledge – field trial studies with HMDs and smart watches have not been conducted in the work context.

The purpose of this study was to propose new technology concepts to support knowledge gathering and sharing during maintenance. Two different industrial maintenance cases were studied, and three technology concepts to support communication were proposed. The paper is organized as follows. Section 2 describes the conducted field studies and Section 3 presents the findings. The three technology concepts are defined in Section 4 and discussed in Section 5. Conclusions are drawn in Section 6.

II. Field Studies

Maintenance work was studied in two cases. The first observation and evaluation session was related to the marine domain, and the second study was made in the crane industry. In both of these, data collection followed the same

Figure 1. Checking the condition and function of an engine's overhaul hatch.

procedure. The data were collected in two phases, by applying a semi-structured interview method and by direct observations of maintenance tasks. Two maintenance workers were observed and interviewed at both sites.

The interviews followed the principles of core-task analysis [23]. The interviews consisted of the following themes: demographics, description of the maintenance activities, safety risks, collaboration, tools and information systems, reporting, procedures and manuals, and tacit knowledge of the work community and maintenance work.

The interviews were audio-recorded and transcribed by a subcontractor. The observations ranged from a general overview of a maintenance site to a selected and detailed maintenance task. In all observation sessions, photos, videos and notes were taken during the process of maintenance tasks. The observations each lasted from one to two hours.

In the first case – solutions for the marine industry (Figure 1) – the focus was on a planned and preventive field service related to engines in a mid-sized oil tanker. The maintenance work included main and auxiliary engine overhauls. The overhaul work was done by seven maintenance workers over a period of two weeks.

The second case was related to a crane company and service activities in their customer's facilities (Figure 2). The crane company's five-membered service team was located in

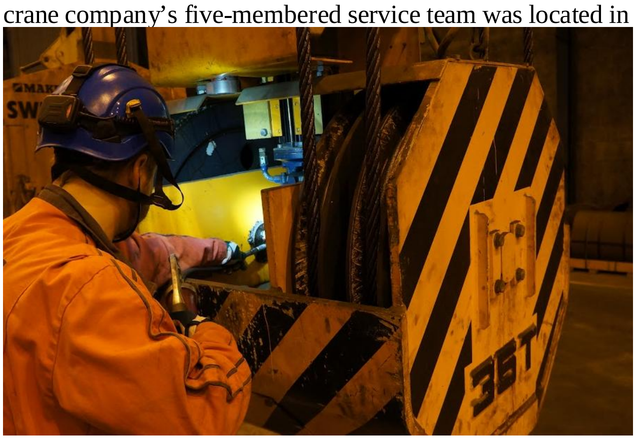

Figure 2. Inspecting and lubricating a hoist system.

a large steel company's factory where the team performed planned and preventive services and on-demand corrective maintenance. Most of the equipment serviced – hoists and cranes – were from the crane company but the team also services other manufacturer's lifting equipment at the customers' facilities.

III. MAINTENANCE WORK IN INDUSTRIAL CASES

Based on the field study, three things arise as core demands in the maintenance task: it is important for the maintenance technician (1) to know the object/product/item and how to repair it; (2) to keep downtime as short as possible; and (3) to have good communication skills. The first two issues are included in the maintenance terminology standard EN 13306 [1] (e.g. time related terms are defined in it), but the communication aspect is not mentioned. The importance of the social and communication related activities in maintenance work have been noted by [24], and was also supported by our findings. Three out of four maintenance technicians answered the question "What are the qualities of a good maintenance technician?" that he/she needs to have good communication skills. Maintenance technicians need to communicate with many people, such as co-workers, technical support and customers. In the marine case, communication can take place with people from the shipyard, the ship's crew, co-workers and also people from other maintenance companies. In addition, there can be several different people who represent one of these groups. In the crane case, the customer was a manufacturing company and their representatives were, for example, the factory foreman and a crane driver. From a model created for knowledge gathering and sharing in maintenance [25], it is possible to see that there are many people (and also other agents) involved in maintenance.

In the studied cases, communication took place mainly face-to-face or via mobile phones: the service technicians asked for help or other information from other co-workers or technical support. According to Orr [26], most of the communication between service technicians is related to the maintenance work they have done to the machines and other work issues such as timetables. Furthermore, service technicians often tell each other stories about past fixes and difficulties in them by a broken machine or over a cup of coffee. Franssila [27] reported that, according to the maintenance technicians, the most reasonable way to share tacit knowledge is face-to-face conversations with people working on the field.

The management of knowledge in the service industry can be challenging. Franssila [27] has listed several challenges, such as (1) the inadequacy of formal documentation; (2) unreliable networks preventing efficient knowledge management; (3) information of new products (e.g., new updates) is difficult to share in the field; and (4) tacit knowledge from the field is difficult to channel to other members in an organization. In our study, maintenance technicians reported that there is a great deal of information available, but sometimes it is difficult to find it from the information systems. It is also possible that the information is in multiple places such as in emails, manuals, notebooks or other systems. In addition, it is sometimes difficult to say whether the information in paper manuals is current and up-to-date. Most of the information gathered from the field is reported in written form. However, maintenance technicians use also their mobile phones to take pictures to add to reports.

Knowledge management in maintenance activities can contribute to the safety and reliability of industrial plants. Dhillon [28] has listed causal factors for critical incidents and reported events concerned with human maintenance errors in power plants, and many of these are directly or indirectly linked to knowledge: faulty procedures, poor unit and equipment identification, poor training and work practices. In addition, Dhillon and Liu [29] have given a comprehensive review of human error in maintenance.

Maintenance technicians need to be skilled workers. Tasks are often technically demanding and safety-critical, and there is always a time pressure. These are reasons for novice workers to work with more experienced co-workers in the beginning. Based on our interviews, most of the learning happens in a real environment from other co-workers: apprentices learn to work with their mentors through observation, imitation and practice. It can also be called on-the-job learning. The use of these approaches means that there is great deal of tacit knowledge that does not transfer just through manuals, instructions or training. In Nonaka's [4] tacit knowledge theory called "Dynamic Theory of Organizational Knowledge Creation", this process of creating tacit knowledge through a shared experience between a novice and an expert is termed "socialization". The modes of knowledge creation introduced in the theory describe the knowledge transfer in our study well.

The context of work creates challenges to the maintenance work. In these two cases, it could be observed that the working environment can be noisy, dark, greasy and hot. Work could also include working in high places (e.g., on the top of cranes) or confined spaces (e.g., inside engines). For example, during the main engine overhaul in the marine case, the maintenance worker had to get inside the engine through a small hatch on its side. In addition, the maintenance work can be performed in an environment where there is other traffic such as automatic vehicles and pedestrians. Technicians also carry different tools such as hand tools, power tools and special measuring instruments with them. In addition, the operating environment can sometimes be too challenging to use smartphones or tablet PCs or laptops, or a wireless network may not be available.

IV. Proposed Technology Concepts

Based on the findings from the field studies, we selected two communication-related themes for investigation: getting help and reporting. Getting help and support from others is one key element in maintenance work. At the moment, it is mainly done by calling other people using a mobile phone. Additionally, reporting is a key element in sharing the knowledge to other people. Currently, the service companies can have several different reporting systems, including the customers' reporting systems, to be completed after the maintenance task. The documentation format is mainly in written form, although some pictures are taken with mobile phones. In addition, writing is done "back" in the office, located some distance from the maintenance site.

Three technology concepts were suggested by the research study group (researchers and company representatives) so as to improve the communication (knowledge sharing) when requesting help/information or reporting. The concepts are: (1) remote assistance; (2) instructions delivery; and (3) data collection/reporting. These technologies were selected based on the company interests and also based on an idea that maintenance technicians have an online access to up-to-date knowledge, and that knowledge can be shared in a more comprehensive and interactive way. There was interest towards many different use cases and, finally two technology concepts were selected for the marine case and one concept for the crane case.

A. Concept 1: Augmented reality guidance

In this concept (Figure 3), the maintenance technician receives help that is available in information systems via a tablet PC and an AR application. In planned and preventive service, the technician goes through a set of tasks. The purpose of this system is to give more comprehensive and interactive instructions to the maintenance technician. The maintenance technician will be given a list of maintenance steps and visual guidance on what to do in the following steps. The system allows the maintenance technicians to proceed at their own pace and acknowledge when a maintenance step is completed. The system therefore ensures that all necessary maintenance procedures are performed, and enables the information to be updated in the customer's system. Other technical support personnel are not needed.

B. Concept 2: Remote assistance

In this concept, technical help is provided to the maintenance technician via a tablet PC (Figure 4). The idea is to support communication and information sharing between different professionals. In maintenance work, technicians can face a situation in which they do not know

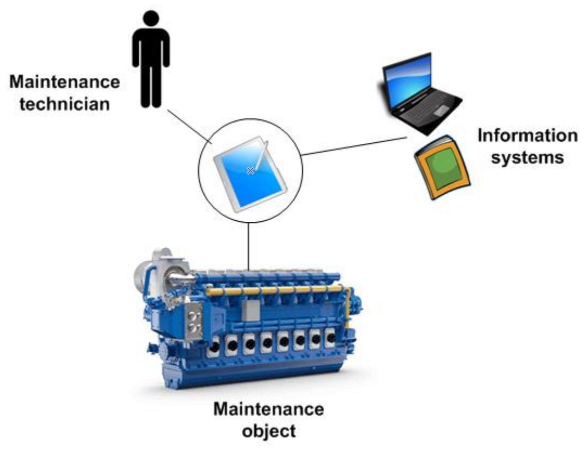

Figure 3. Augmented reality guidance concept

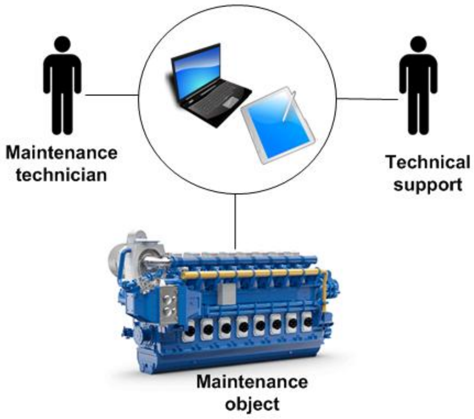

Figure 4. Remote assistance concept

how to proceed or else need support in doing so. A similar situation occurs when there is no guidance on a specific tool nor written instructions on the values of how a certain system is trimmed. In these situations, the technicians typically call their colleagues for help. The purpose of the remote assistance system is to support the maintenance technician on site. The maintenance technician will receive help and advice online from a technical support person located in a remote office. The maintenance technician will use the tablet PC and its camera as a medium to transfer images or video of the object being maintained. He/she can discuss with the technical support and be given visual indicators to the images on the tablet on how and with which components to proceed next. They are able to share the same visual image of the maintenance object. The system can also be implemented using AR technology, which – presumably – makes it easier for the technician to locate the targeted objects. The technical support will use a computer to see what the maintenance technician is doing and give instructions to him/her. The support person can also ask the technician to reposition the tablet's camera to a better viewing angle. This type of system gives the possibility for the related information to be saved to an information system for later access.

C. Concept 3: Data collection and reporting

In this concept (Figure 5), the communication between information systems and a maintenance technician is maintained using wearable devices. The concept utilizes a combination of three different wearable devices: a smart phone, a smart watch and smart glasses. The system facilitates checking information on the work tasks and maintenance object on-site. The maintenance procedures performed need to be reported back to the customer's information system. This concept was proposed in order to make reporting easier on site and to shorten the reporting time. With the smart watch, the maintenance technician is able to select the maintained object and component from a structured interface, and choose either picture-taking or

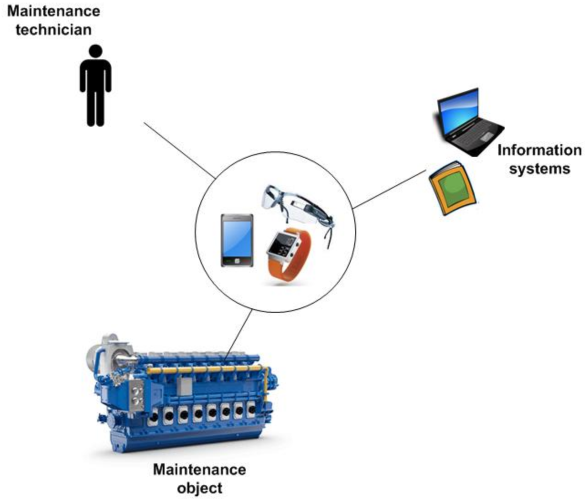

Figure 5. Data collection and reporting concept

error reporting, which are directly linked to the component selected. The smart glasses are used for checking information and taking pictures hands-free. The smart phone is used for adding text to the reports and for locating a maintenance target. This concept supports working in conditions where both hands are needed, and enables fast online reporting. It can also be used in situations when the technician needs information on earlier procedures, or numerical and statistical data on the functioning of the object maintained.

D. Traditional and envisaged practices

The difference between traditional and envisaged practices is illustrated in Figure 6. In addition, we hypothesize that benefits are gained from improvements in the quality of knowledge sharing and time savings in reporting.

V. DISCUSSION

The purpose of this study was to understand the key features and requirements in maintenance work, and to propose new technology concepts to support knowledge gathering and sharing during maintenance. Based on the studies, it was found that social and communicational aspects are also important in maintenance work. Therefore, the project group focused on developing new technology concepts to support these aspects, especially the activities of getting help and reporting. Finally, three technology concepts were proposed and they are discussed here.

The augmented reality guidance concept is quite thoroughly researched as an instruction delivery tool in many studies [6][7][8][9][10][11][12][13][30][31]. Those results suggest that AR technologies are usable in providing instructions. In particular, this concept can be useful in demanding maintenance tasks that are rarely carried out or in situations where it is not possible to contact other people.

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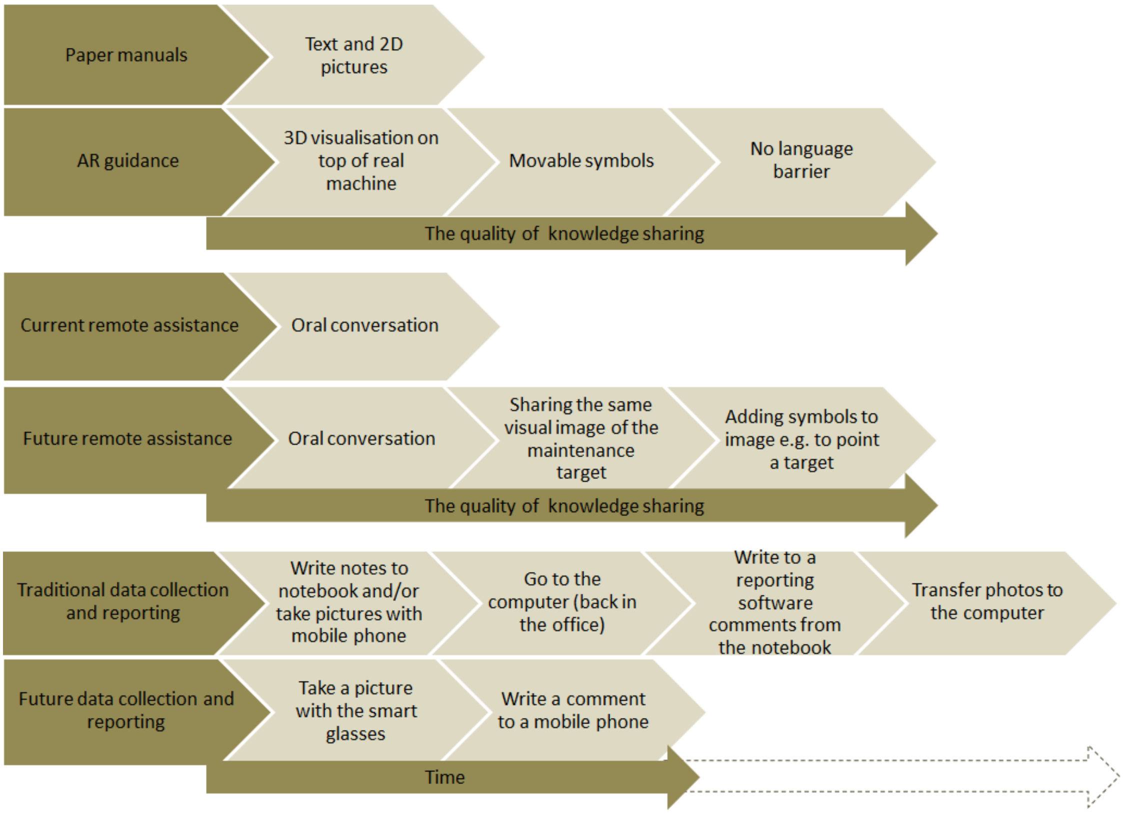

Figure 6. Comparison of current and future maintenance practices . The arrows show the expected benefits.

One of the advantages of this concept is that these instructions are easier to keep updated, and they can be more illustrative than paper manuals. It is possible, however, that this kind of technology concept is usable only in rare cases. Usually the maintenance staff is skilled and do not need instructions, or if help is needed, it is easier and faster to call a colleague. The selection of a medium for this purpose is also an issue, e.g., is the tablet-PC the best medium?. Similarly, it is also important to thoroughly consider how the information is presented in the AR solution [32].

The remote assistance concept is promising in the sense that it makes it possible to share the same visual image of the situation with others [15][16]. In addition, positive results have been reported using shared visual 3D images during the design [33][34][35]. In these studies, a virtual representation of the design object has supported knowledge sharing and provided a platform to communicate with each other in a more intuitive way. The intuitiveness is supported by the remote assistance concept by enabling a technical support person to point out some essential objects or give other interactive guidance. Compared to the currently used mobile phone calls this brings knowledge sharing closer to Nonaka's [4] "socialization" mode of creating knowledge in which tacit knowledge is created through shared experience. A possible challenge in this concept is that an online connection may not be available or it does not work reliably and uninterrupted. Furthermore, advanced remote assistance communication may take more time than using a mobile phone and increase distraction from the maintenance work.

The concept of using wearables for data collection and reporting has a chance to shorten the reporting time and improve the quality of the knowledge sharing to the customers and other people reading the reports. The expected benefit is in the automation of time-consuming secondary tasks in maintenance. Another benefit in this concept is the aim to keep maintenance both of the technicians' hands free so that they can focus on performing repair tasks. The working environment may require free hands, e.g., when using tools, climbing stairs or supporting oneself with the railings in high places. However, wearable devices have very limited screen sizes and input methods: a touch screen or gesture recognition may not be applicable in all demanding maintenance environments. Challenges can also arise from the simultaneous use of multiple devices and the selection of the best technology combination for maintenance work.

The adoption of new technologies may generate new benefits for various stakeholders such as maintenance technicians, companies and/or customers. Most of the benefits for maintenance technicians derive from the availability of up-to-date knowledge, and automated secondary tasks. Therefore, the maintenance technicians can focus on their core tasks, and allow them to work more safely, and work faster and with less mistakes and frustration. At the service company level, this will provide benefits such as improved productivity and better quality in maintenance. Customers will gain most benefits from short downtime in production, better scheduled services and enhanced communication with the maintenance company.

These concepts are the first showcases of the iterative design process. In the future, the concepts will be tested in the field so as to analyse their potential in supporting knowledge gathering and sharing during maintenance. Next, showcase generation and demonstration systems will be developed based on the results gathered from the analyses.

The field studies will be performed in real usage environments with real end users, i.e., service technicians. Two technicians will test each concept. Because of the small number of test participants, a qualitative approach for evaluation is needed, and therefore the subjective opinion of the technicians – with their knowledge and practical experience of working in the field – will be the starting point. The field study will include an experimental part with demonstrators, followed by a customized questionnaire with a subjective rating scale (a combination of Technology Acceptance Model (TAM Satisfaction Questionnaire) [36] and usability questions modified from System Usability Scale [37], and interviews. The interviews will include questions concerning the added-value to the technicians' work, and training needs, work practices and future expectations of the technicians. In the demonstrator testing phase, the qualitative evaluations are expected to give a broader set of results than could be achieved with quantitative performance metrics (e.g., time elapsed in maintenance, time spent with communicating with technical support or using the technology), which are more useful in later phases of the design process.

VI. CONCLUSIONS

Industrial maintenance is a complex and knowledge-intensive field. Maintenance technicians need to have easy access to versatile and situationally relevant knowledge. The aim of this paper was to understand key features in maintenance work and to propose new technology concepts to support knowledge gathering and sharing during maintenance.

Maintenance work was studied in marine and crane industry cases. The data were collected by interviews and direct observations of maintenance tasks were recorded. As a result of these studies, it was elicited that communication between different actors is a key element in the maintenance, in addition to more self-explanatory activities such as repairing a maintenance object. Finally, three technology concepts were suggested to support communication and knowledge sharing: (1) augmented reality guidance, (2) remote assistance, and (3) data collection and reporting with wearables.

This is an on-going research project. In the next phase, demonstrators will be developed based on the suggested concepts and tested in the field with service technicians. Findings from this study can be used to improve the understanding of the social and communication aspects in maintenance work. In addition, the technology concepts are usable in other domains, such as design and assembly, to improve knowledge gathering and sharing.

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